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DESIGN AND OPERATION OF A BIOCLIMATIC CABINET FOR SIMULATING VARIABLE TEMPERATURE, HUMIDITY, AND LIGHT CONDITIONS [1]

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The growing demand for information covering improvements in our bioclimatic chamber design and operation has suggested a need for revision of an earlier description of the cabinets issued by Flitters, et al.[2] More efficient and economical operation of the present chambers is possible because of simplification and refinement of mechanical controls and instrumentation. Standard commercial refrigerators have also been converted into environmental chambers at comparatively low cost. Controlled lighting is an added feature. This publication contains a description of the cabinets as now used.

Cabinet Construction

The overall dimensions of the cabinets (fig. 1), including the refrigeration equipment and control panel, remain unchanged. The cabinets are 11 feet 8 inches long by 9 feet 8 inches wide by 7 feet $7\frac{1}{4}$ inches high. They are of sectional knockdown construction, with 6 inches of Fiberglass [3] insulation between $\frac{1}{2}$-inch layers of plywood, and an additional lining of 15-pound, vaporproof, building paper backing the outer plywood layer. The upper layer of the insulated floor is of 5/8-inch exterior plywood. The exterior plywood walls of the cabinet are painted with three coats of glossy white enamel, and the interior is lined with stainless steel with all seams sealed. The floor is provided with a single drain. The inner chamber is 6 feet square and $6\frac{1}{2}$ feet high.

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[1] In cooperation with the California and Texas Agricultural Experiment Stations.

[2] Flitters, N. E., Messenger, P. S., and Husman, C. N. Bioclimatic Cabinets Used in Studies of the Mexican Fruit Fly and the Pink Bollworm. U.S. Dept. Agr. ARS-33-33, 12 pp. 1956.

[3] Mention of a proprietary product in this publication does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture, and does not imply its approval by the Department to the exclusion of other products that may also be suitable.

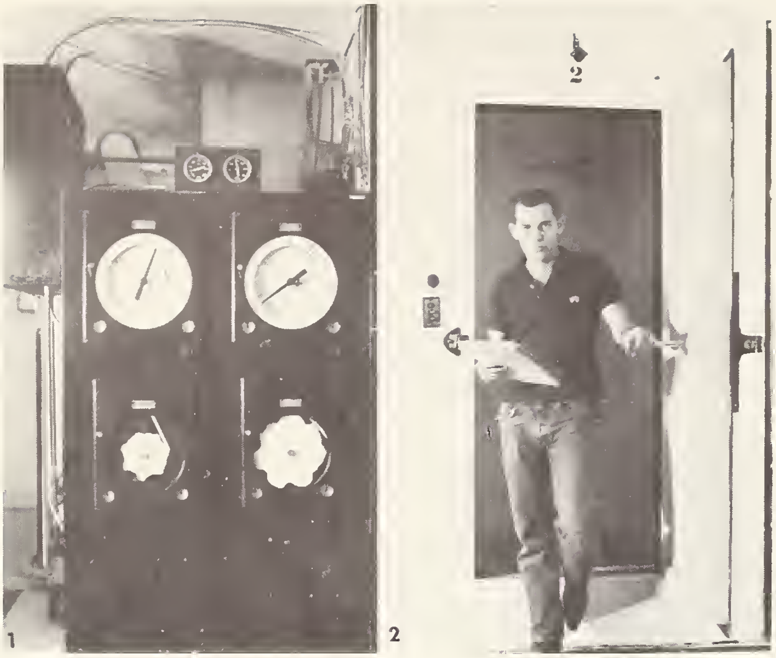

Figure 1.--A bioclimatic cabinet, showing (1)temperature and relative humidity transmitters and recorders, and (2)entrance door vestibule.

One refrigerator-type door of construction similar to that of the walls, with stainless-steel inner surface, and an opening approximately 2 feet 6 inches wide and 5 feet 9 inches high, opens outward into an anteroom. The anteroom measures 4 feet square, in side dimensions, and is of the same height and construction as the main room. It is equipped with an outer, heavy refrigerator door, similar to that used in the inner chamber but without the stainless-steel lining.

Opposite the door are two windows providing a total viewing surface of 15 square feet. Each window consists of three noncondensing plate glass panes $\frac{1}{4}$-inch apart with the space between evacuated.

Lighting has been improved by the installation of 42 slimline, 38-watt, F 64T6 fluorescent tubes, interspersed with 19 incandescent, 40-watt bulbs (fig. 2) in the ceiling of each cabinet. The fluorescent lights are equally divided into three banks, each of which is actuated by an interval timer that can be set for from 15-minute to 12-hour intervals. There is thus provided the means for reducing light needed for the production of insects and plants, for simulating sunrise and sunset, and for making corrections for the normal declination of the sun.

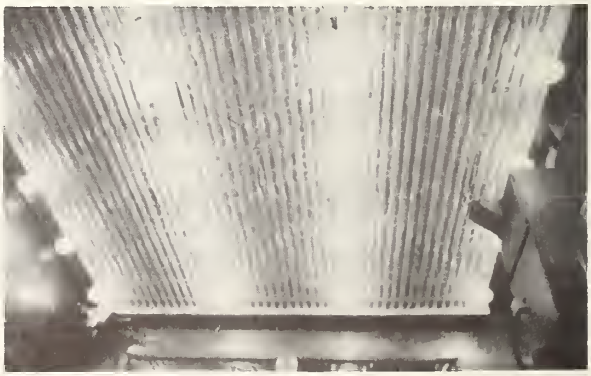

Figure 2.--Bioclimatic cabinet interior showing illumination in ceiling for providing controlled photoperiods.

A weatherproof socket for a standard light bulb is installed in the corner of each room near the door, and directly below it near the floor is a weatherproof convenience outlet.

Mounted on the interior wall of each cabinet is an electric humidity-sensing element and over that, a stainless-steel aspirator receptacle containing a small, squirrel-cage blower that draws air over a copper constantan thermocouple for temperature sensing.

Air-Conditioning Equipment

The refrigeration equipment is much like that covered in the original description. The refrigeration compressor is powered by a 10-horsepower, two-speed motor, 1,450 and 725 r.p.m. Monochlorodifluoromethane 22 is used as the refrigerant. This compressor has automatic capacity unloading, permitting from one to four of its cylinders to operate, depending upon the load. It is provided with water-cooled cylinder heads to prevent overheating when operating at low-suction pressures.

An 80-gallon-per-minute water pump--a new addition to the supply line running from an atmospheric cooling tower to the condensers--circulates water evenly to each condenser. The tower, a redwood louvered unit, 4 feet wide by 8 feet long by 12 feet high, with a 2-foot water reservoir, is protected from strong prevailing south and southeast winds by barriers of 1-inch by 8-inch planks alternately spaced on telephone pole uprights.

Enclosed in an insulated cabinet built onto one wall of each bioclimatic cabinet are two air-handling units mounted side by side with an insulated partition between them. One of these is shown in figure 3. Access to each unit is provided by a removable panel

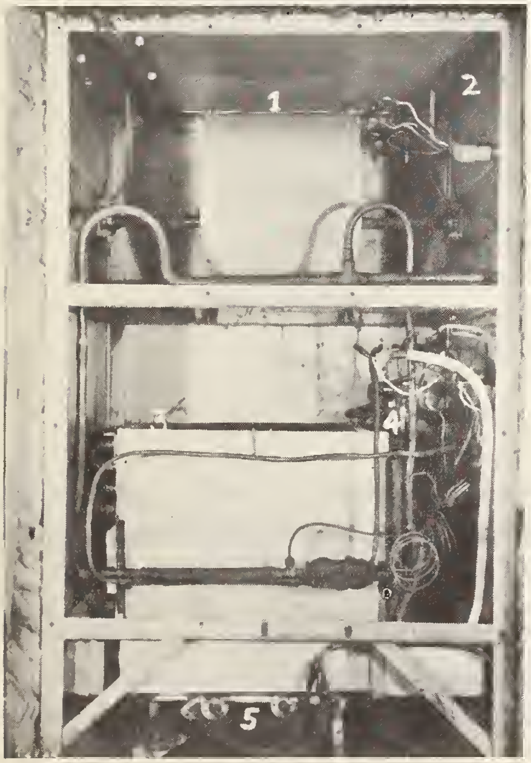

Figure 3.--Air-handling unit, left side, showing (1) squirrel-cage blower, (2) heater wiring in duct, (3) refrigeration lines, (4) expansion valves and cooling coil, (5) defrost heaters beneath coil.

in which is installed an outside air intake with adjustable damper. Two supply registers, located in the interior working space of the cabinet, adjust to control the volume and direction of the circulating air. Both the supply and return air grilles are cadmium-plated to prevent corrosion.

Each unit is equipped with a large expansion coil having copper tubes and aluminum fins with $\frac{1}{4}$-inch spacing, and over each unit there is a $\frac{1}{2}$-horsepower, 3-phase motor driving a squirrel-cage blower. Each coil is divided into three sections, and each section is provided with an expansion valve so that there are three refrigerant circuits. Two circuits each have one-fifth, and one circuit has three-fifths, of the total refrigerating surface. By various combinations of these circuits it is possible to obtain increments of refrigeration in fifths of the total capacity of the coil. The first two refrigeration circuits are controlled by thermostatic expansion valves of 1-ton capacity, and the third circuit by a valve of 3-ton capacity. A diagram of the cyclic operation of the air-handling units is shown in figure 4.

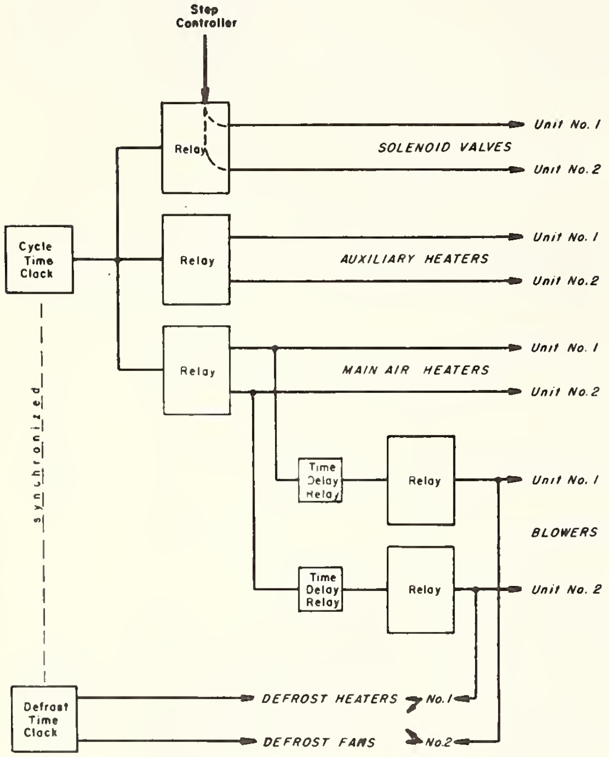

Figure 4.--Diagram showing cyclic operation of air-handling units.

Four 375-watt, copper-encased, immersion-type electric heaters are installed just below the refrigerant coil of each air-handling unit. The heat rising through the coil during the defrost period is sufficient to melt any ice or frost that accumulates.

Beneath the refrigeration coil of each unit there is a stainless steel pan to collect the water that accumulates during the defrost cycle. The water is carried through a trap to a floor drain situated beneath the refrigeration coil housing.

Humidity is supplied to the cabinets by means of steam, regulated by modulating steam valves and solenoid valves (fig. 5). The injected steam is immediately circulated within the main room of the cabinet by a squirrel-cage blower.

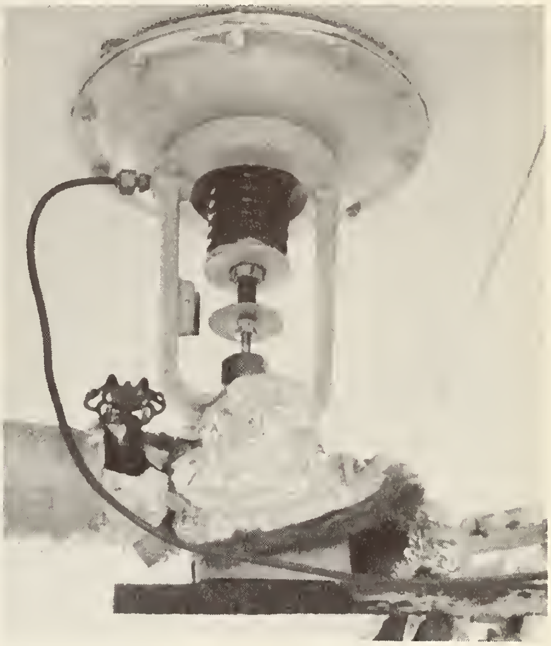

Figure 5.--Steam supply line, solenoid valve, and modulating steam valve, which together regulate the amount of steam entering the cabinet to control relative humidity.

Control Equipment

Only minor improvements have been made in the control equipment needed to operate the bioclimatic cabinets. A heavy sheet-metal panel for mounting control instruments and attendant relays and accessories has been installed adjacent to the anteroom, and facing the front of the cabinet. On this panel there are two time-pattern transmitters and two circular chart controller-recorders, one each for temperature and humidity. These instruments operate on 115-volt, 60-cycle current, and require compressed air at 30 p.s.i. On the rear of the panel are five pneumatic-electric relay switches for controlling solenoid valves in the air-conditioning system, and a diverting air relay for controlling the opening of a modulating steam valve, as well as the necessary air pipelines, air-reducer valves and drip wells, and electrical connections (fig. 6). On the outside cabinet wall adjoining this panel are four pneumatic-electric relay switches to control the heating system.

Two 5-horsepower air compressors, one of them used as an auxiliary, supply air for the instruments and controls. A dehumidifying filter has been installed in the air-supply line to the cabinets.

The operation and the interrelationships between these control instruments are described in the section on control sequence.

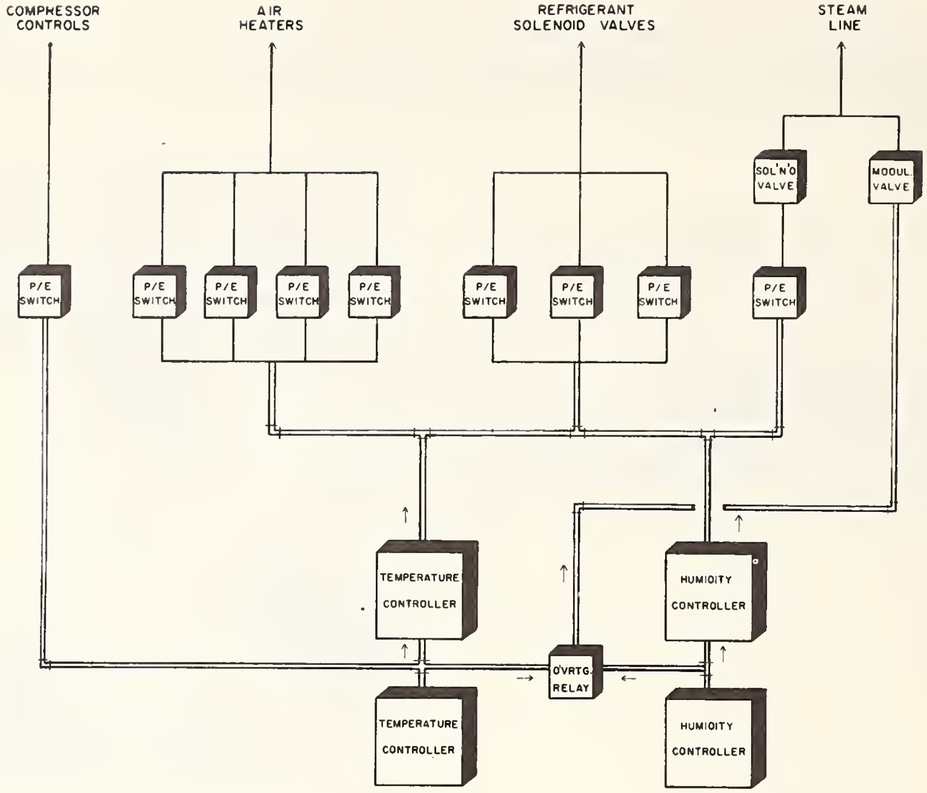

Figure 6.--Diagram showing control system viewed from rear of sheet metal control panel.

At the side of the main panel is the electric panel (fig. 7) housed in a heavy metal cabinet with lock door. On this electric panel are fuse blocks, a two-speed magnetic starter for the compressor, a time clock for the air-conditioning unit cycle change, relays, and an interval timer for operating the refrigeration solenoid valve controls. At the bottom are two time-delay relays to control the blowers on cycling of units, and two blower magnetic starters. On the forward end of the panel, so as to be viewed from the front of the cabinet, are indicator lights that show which air-handling unit is in operation, how many refrigeration circuits are on, and when moisture is being introduced into the cabinet. Below these lights are switches to control the cycling of the units, operation of the defrost coil, and on-off switch for the compressor. An additional safety switch to control the operation of the compressor is mounted on the panel. Both low and high-temperature thermostats are located in the interior of the cabinet. Should temperatures lower than demanded by the transmitter occur, a relay mounted on the panel cuts off refrigeration; if temperatures higher than required occur, another relay wired to the lights and heaters becomes energized and cuts off these two units. Wired into this system is an alarm buzzer located on the wall of the laboratory which is activated whenever these malfunctions occur, and a red light is immediately switched on above the door of the cabinet experiencing the trouble.

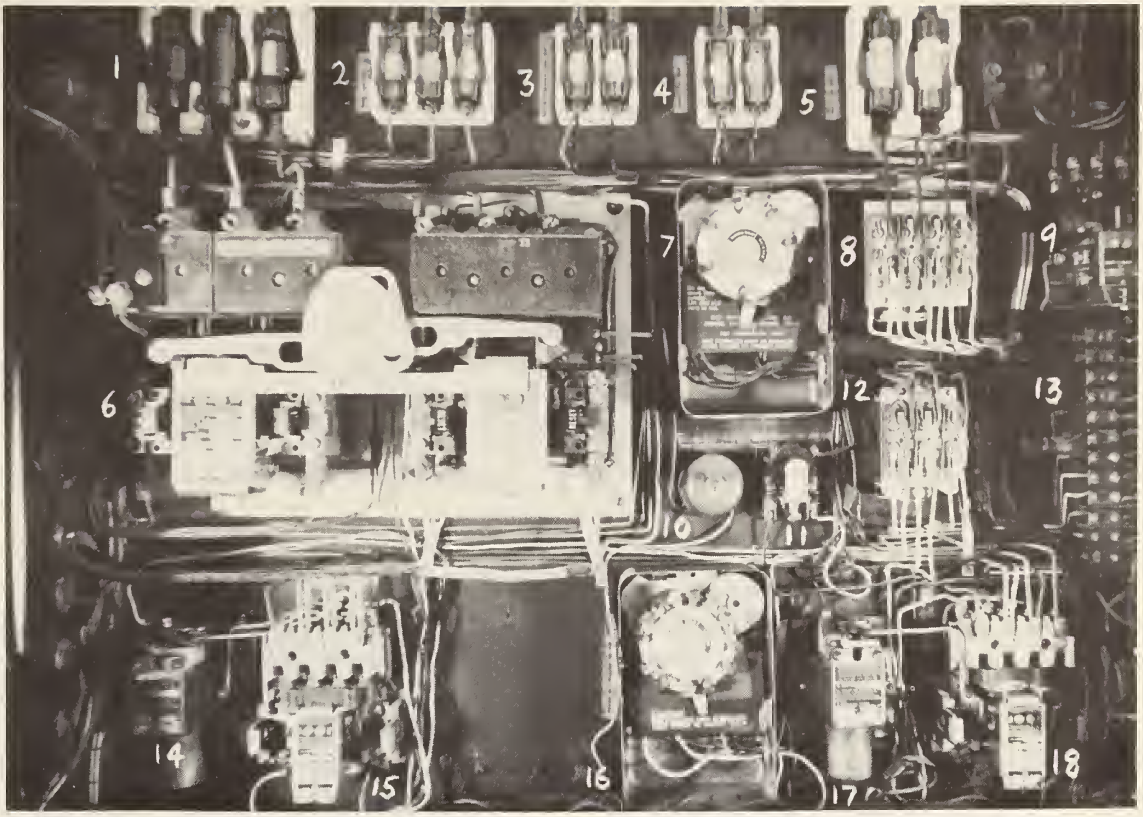

Figure 7.--Main electric panel of a bioclimatic cabinet, showing (1)compressor fuse block, (2)air-handling unit blower fuse block, (3)heater-condenser fuse block, (4)control fuse block, (5)heater fuse block, (6)two-speed compressor motor starter, (7)cycle-change timeclock, (8)change-over relay heaters, (9) heater disconnect, (10)compressor positive-off safety switch, (11)defrost relay, (12)change-over relay, refrigerant solenoid valves, (13)terminal block, (14)time-delay relay for unit No. 2, (15)blower magnetic starter for unit No. 2, (16)defrost timeclock, (17)time-delay relay for unit No. 1, (18)blower magnetic starter for unit No. 1.

Heaters and Refrigerator Step Control

Installed in the air duct entering the cabinet from the refrigeration units are four 1500-watt, 230-volt, heating elements, each connected to a pneumatic-electric switch, which is controlled by air pressures from the instrument temperature transmitter.

Control Sequence

One time-pattern transmitter, located on the control panel, has an arm which follows the curvature of a cam shaped to give the desired temperature to be maintained in the cabinet. This transmitter produces an air signal ranging from 0 to 14 p.s.i. over the range of the instrument, which is from -50° to $+ 150^{\circ}$F. This signal is passed to the temperature controller-recorder installed above it.

If the temperature in the cabinet is below that desired, the air-pressure signal is built up by the recorder and is passed through four pneumatic-electric switches that in turn activate the electric air heaters, which bring the conditions back to the control point. If the cabinet is warmer than indicated by the index on the instrument dial, the transmitted air signal decreases, and when it falls below 6 p.s.i., the refrigeration is turned on. The temperature can be raised or lowered as much as 40°F. in 60 minutes.

A time-pattern transmitter controls humidity in the same manner as that for temperature. This instrument passes a signal corresponding to any desired humidity. As the follower arm on the cam cannot climb a gradient of more than 70 percent, and natural humidity patterns often present greater rises, the linkage has been changed to give a full range of signals, using only the outer third of the regular cam. This signal is transmitted to a humidity controller-recorder directly above it. A humidity-sensing element in the aspirator box within the bioclimatic cabinet measures the relative humidity therein and transmits this R.H. value to the control panel. This element, an electric hygrometer, is accurate to within ± 2° F. of dew point through a range of 9 to 95 percent.

Should the humidity be below that desired, the air signal from the humidity controller will build up. This air signal is then transmitted to a pneumatic-electric relay, which makes contact at 13.5 p.s.i. and operates the steam solenoid valve. Should the humidity be above that desired, the transmitted air signal decreases, and since this signal is interconnected with the air signal from the temperature controller-recorder through a diverting relay that transmits the lower output from either instrument, the refrigeration cycle is brought into operation exactly as the temperature control. Complete saturation is possible within a few minutes at temperatures lower than 100° F., and the humidity can be lowered as much as 60 percent per hour.

A steam-control valve that modulates the quantity of vapor flowing through the steam solenoid is positioned by the transmitted air signals from the time-pattern transmitters.

A pneumatic-electric relay, connected into the air line from the temperature transmitter, controls the compressor speed. High speed is obtained when the temperature drops to 30°F. or below, and low speed when it rises to 49°.

Cycle Changing

To provide for alternate operation and defrosting of the two air-handling units, two time clocks are provided (fig. 6). The main control time clock alternates the operation from one air-handling unit to the other after it has been in operation for any selected period. These periods may extend from 1 to 12 hours. An electrical time-delay relay in the circuit to the blower prevents it from starting for approximately 10 seconds after each cycle change. This permits the refrigerant to chill the coil, or the heaters to warm up, before the blower starts, thereby eliminating undesired disturbances in chamber-air control due to delays in performance of these units.

The second time clock controls the operation of the defrost heaters and auxiliary fans. Approximately 15 minutes after a cycle change, this clock turns on the defrost heater of the unit that has just gone out of service, and after 1 hour it turns off the defrost heater and turns on the auxiliary fan to dry the coil and return it to room temperature. The auxiliary fan continues to operate until about 15 minutes after the next cycle change when the defrost cable on the other unit is then turned on.

CONVERSION OF STANDARD WALK-IN REFRIGERATORS TO VARIABLE-TEMPERATURE AND RELATIVE-HUMIDITY CABINETS

Standard walk-in refrigerators, cooled by means of dual $\frac{3}{4}$-ton refrigerator compressors, each driven with a 1-horsepower motor, were converted into variable-temperature and relative-humidity, environmental chambers. These refrigerators are 8 feet square by 7 feet 6 inches high on the outside, and 7 feet 4 inches square by 7 feet high on the inside. One door, 3 feet wide and 6 feet high, provides access to the room.

The overall dimensions of the cabinets (fig. 8), including refrigeration equipment and control panel, are 11 feet 7 inches by 8 feet. The wall and ceiling panels are of portable design, with 4 inches of Fiberglass insulation between the metal exterior and interior walls. The exterior of the cabinet is painted with three coats of glossy white enamel and the interior primed with rust-inhibiting paint over which two coats of white enamel are applied. Installed in one wall is a window, 3 feet square, consisting of three panes of noncondensing glass, with the air between each evacuated. The cabinets are raised 6 inches above the floor on hardwood joists to allow air to circulate beneath the floor and facilitate the flow of water from a drain situated in the interior of the cabinet. The floor is pitched to the drain which is located in the center of the room.

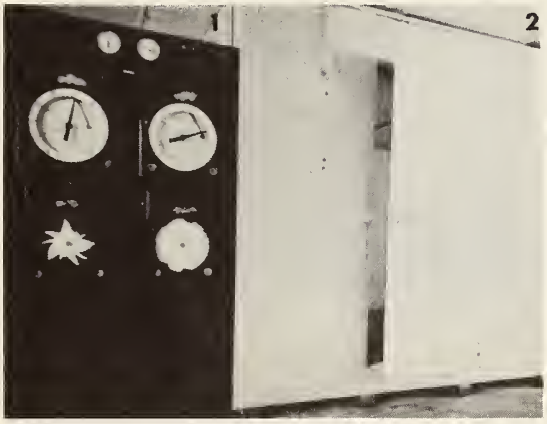

Figure 8.--Converted refrigerator, showing (1)temperature and relative humidity transmitters and recorders, (2)entrance door.

Four banks of lights containing a total of 40, 72-inch, 40-watt, daylight fluorescent tubes and 25, 40-watt, incandescent bulbs are suspended from the ceiling (fig. 9). Three panels of 0.005-inch Mylar[3] polyester film are mounted directly beneath the lights to seal off the heat generated by them. A flow of air is circulated by a 1/3-horsepower, squirrel-cage blower through the banks of light bulbs and over the Mylar film, and is discharged into a duct that carries it outdoors. A standard 1-inch thick refrigeration filter and an electrostatic filter are placed one upon the other in the air-intake duct.

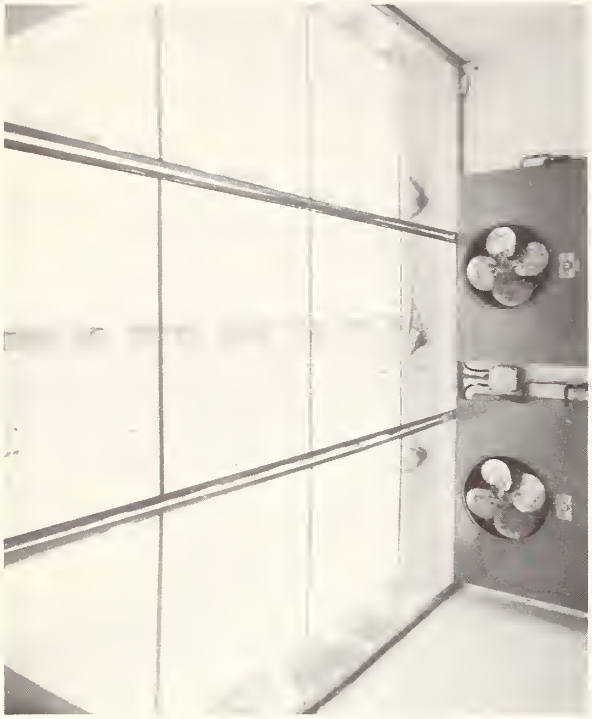

Figure 9.--Converted refrigerator interior, showing illumination for providing controlled photoperiods, and Mylar plastic heat barrier.

Photoperiod and light intensity are controlled by three standard electric timeclocks. These clocks are set to provide light in increments of 100 - 2000 ft.-c. evenly distributed over the entire room. The fluorescent tubes are wired to the ballasts to insure that alternate pairs of tubes are activated by the timeclocks. The incandescent bulbs are operated as a unit by a fourth timeclock.

Temperature and relative humidity are sensed by a thermocouple and an electric hygrometer situated in an aspirator cabinet containing a small blower which pulls air over the sensing elements.

The refrigeration compressor for one cabinet is powered by a 3-horsepower motor; the other, by a 2-horsepower motor. Monochlorodifluoromethane 12 is used as the refrigerant. In addition, the dual $\frac{3}{4}$-ton refrigeration systems that are standard equipment on the refrigerator units are used to augment the above-mentiond compressors. Water is supplied to the condensing units from the atmospheric cooling tower described previously.

A 4-row direct expansion coil with dual fans, standard equipment with the refrigerator, is mounted on the inside wall of each cabinet. Directly beneath this unit on the floor of each cabinet, a unit cooler has been installed. This unit is designed to operate from the added 2- or 3-horsepower refrigerator compressor, which gives it a rated capacity of 9,400 or 12,000 B.t.u./hr. 10° T.D., respectively. Each unit is equipped with a hot gas defrost system controlled by a time clock.

On a pneumatic signal from the recorder-controller for cooling, a pneumatic-electric switch operates the refrigerant solenoid valve on the new unit cooler to admit refrigerant to the cooling coil. On a further signal for added cooling or supplemental cooling during the primary coil defrost, a second pneumatic-electric switch operates a solenoid valve on each of the dual units and places them in operation (figs. 10 and 11).

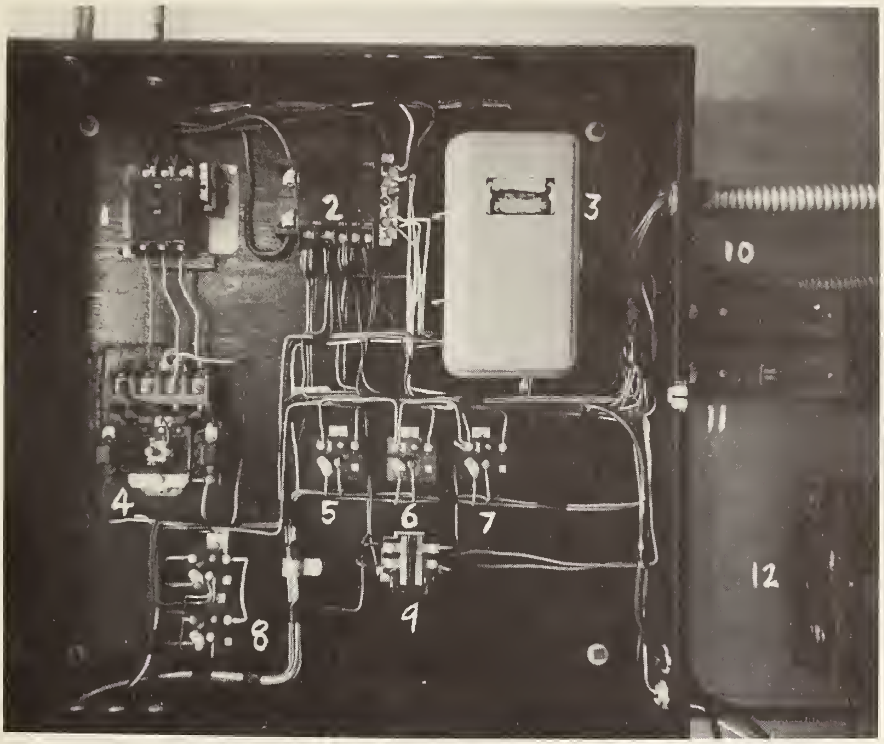

Figure 10.--Main electric control panel of converted refrigerator, showing (1) breaker switch, (2) breakers--heating, blower, instrument panel, and solenoids, (3) defrost timeclock, (4) compressor starting relay, (5) heating relay, (6) heating relay, (7) heating relay, (8) defrost solenoid relay, (9) blower relay, (10) high-temperature thermostat, (11) low-temperature thermostat, (12) constant voltage regulator.

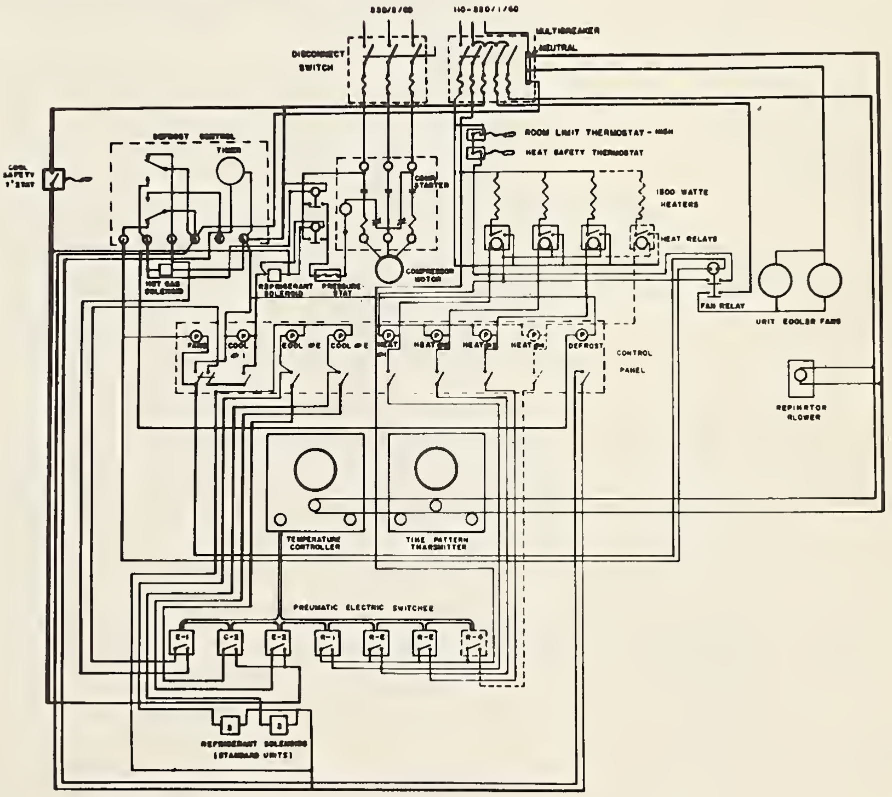

Figure 11.--Diagram showing control system for converted refrigerators.

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Four 1,500-watt electric heating elements, protected by an expanded metal grille, are situated in front of each cooling coil. Circulating fans help distribute the heat.

Installed in each cabinet are two thermostats, one which cuts off the heating elements and lights should the room temperature rise above the desired maximum, and one which cuts off refrigeration should the temperature fall below the desired minimum. These thermostats are regulated to fit the patterns of temperature to be simulated each week. Each thermostat is wired into a circuit that energizes a 10-watt light bulb located on the exterior of the cabinet, and causes an alarm bell to ring when either a low- or high-temperature malfunction occurs.

SUMMARY

The specially designed bioclimatic cabinets being used at Brownsville, Tex. to determine the effect of temperature, relative humidity, and photoperiod on the behavior and perpetuation of insects and other arthropods, have been modified to provide refinement of control and improved lighting. Walk-in-type refrigerators have been converted into variable-temperature, controlled-environment cabinets with improved lighting facilities.

Temperature and humidity conditions are maintained by water-cooled compressors on the specially designed, bioclimatic chambers, and by a combination of water-cooled and air-cooled compressors on the converted walk-in refrigerators. Electric nichrome wire elements supply the required heat, and steam-injection nozzles, activated by pneumatic-electric controllers, provide the relative humidity requirements.

All controls are activated from a pneumatic-electric instrument panel that transmits, through the medium of cams, the desired temperature and relative-humidity patterns. An effective biological spectrum is provided by balanced fluorescent and incandescent lighting. Length of photoperiod and intensity of light are controlled by time clocks.

To accomplish automatic defrosting, dual cooling and drying coils are operated by timeclocks over intervals of 2 to 12 hours; the deactivated coil is both defrosted and dried while the other is in operation. The converted refrigerators are equipped with a hot gas defrost on the water-cooled compressor coils, and by heating elements on the air-cooled system.